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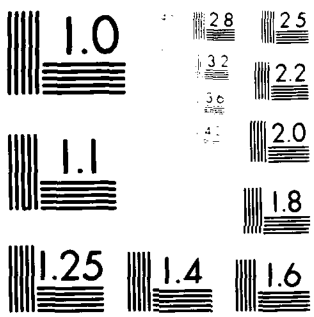

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the third program year emphasis of research was placed six subareas, namely, very high scanning-rate light beam deflection/switching, spectrum analysis of very wideband RF signals, wideband AO Bragg cell using multiple tilted transducer but without electronic phase shifters, wideband AO Bragg cell using a tilted-finger chirp transducer, improvement in fabrication capability, and acoustooptic Bragg deflection in crossed channel optical waveguides. Major progress and achievements for each are ~~now~~ described.

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1. Very High Scanning-Rate AO Light Beam Deflection and Switching

During the course of experiments aimed at achieving a higher scanning rate and a large number of beam position, two transducer configurations capable of producing wideband AO deflection, namely, tilted-finger chirp transducer and curved transducer of varing finger periodicity were discovered.

2. Spectrum Analysis of Very Wideband RF Signals

A coupled-mode analysis relevant to Guided-Wave AO Spectrum Analysis has been completed. Measurements on number of resolvable channels and frequency resolution were made using a Bragg cell with 680 MHz bandwidth. Desirable data was obtained.

3. Wideband AO Bragg Cell Using Multiple Tilted Transducer But Without Electronic Phase Shifters

We have discovered a simple scheme (in conjunction with multiple tilted-transducers) to obtain a broad deflector bandwidth (680MHz) without requiring electronic phase shifters. This is the largest bandwidth that has been reported.

4. Wideband AO Bragg Cell Using a Tilted-Finger Chirp Transducer

A tilted-finger chirp transducer which had evolved from the multiple tilted-tranducers has been shown to be capable of providing wideband AO light beam deflection.

5. Improvement in Fabrication Capability

We can now fabricate SAW transducers with center frequency approaching 1 GHz.

6. Acoustooptic Bragg Deflection in Crossed Channel Optical Waveguides

We have opened up a new area of research in Guided-Wave Acoustooptic which involves channel optical waveguides rather than planar optical waveguides. The premilinary results obtained have been very encouraging. The resulting devices should find a variety of unique applications in future integrated and fiber optic systems such as double-pole-double-throw switching, multiplexing/demultiplexing, heterodyne detection, and fiber optic sensing.

AFOSR-TR- 81-0432

THIN-FILM ACOUSTOOPTIC AND ELECTROOPTIC DEVICES WITH APPLICATIONS TO INTEGRATED/FIBER OPTIC SIGNAL PROCESSNING AND COMMUNICATIONS

Final Technical Report

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For the Period

1 January 1979 - 30 September 1980

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THIN-FILM ACOUSTOOPTIC AND ELECTROOPTIC DEVICES WITH
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SIGNAL PROCESSING AND COMMUNICATIONS

Final Technical Report

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THIN-FILM ACOUSTOOPTIC AND ELECTROOPTIC DEVICES WITH APPLICATIONS TO INTEGRATED/FIBER OPTIC SIGNAL PROCESSING AND COMMUNICATIONS

Interim Scientific Report III

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1. INTRODUCTION - THE POTENTIAL OF INTEGRATED AND GUIDED-WAVE OPTICS

Integrated/Guided-Wave Optics is an emerging science and technology that has been actively pursued in recent years. The ultimate objective of integrated optics is to realize miniature optical components such as light sources, modulators, switches, deflectors, lenses, prisms, and detectors in a substrate to perform various unique functions. Like the existing integrated electronics in which a large number of active and passive components such as transistors, diodes, resistors and capacitors are packed in a small semiconductor chip, the ultimate integrated optic circuits and systems are expected to have many advantages over the conventional bulk optical systems. Some of the advantages include smaller size and lighter weight, wider bandwidth, lesser electrical drive power requirement, greater signal accessibility, and integratability. The integrated optic circuits are also expected to possess advantages in stability, reliability, ruggedness and ultimate cost.

It has now been well recognized that the most immediate and important applications of integrated optics lie in the areas of wideband multichannel communications and signal processing (for both civilian applications such as fiber optic systems and military hardwares such as radars). With regard to communications, a number of first-generation low-data rate laboratory and field test systems have been built and their measured performances have been most encouraging. With regard to signal processings, the research on Wideband Guided-Wave Acoustooptic Devices carried out by this principal investigator and others has paved the way for a number of unique applications.[1,2]

II. RESEARCH OBJECTIVES

The aforementioned preliminary successes have clearly indicated that various kinds of high-performance active optical devices such as high-speed multichannel deflectors/switches and modulators are needed for the realization of these two areas of applications. For example, one of the important functions of an optical receiver terminal is the routing or fanning-out of incoming optical signals to a large number of separate channels or users. Another example is the Integrated Optic RF Spectrum Analyzer being actively pursued. Miniature optical devices, aside from being smaller and lighter, can potentially perform these functions in a simpler manner, at a faster speed, and at lesser cost. Thus, the general objective of the AFOSR-sponsored research is to discover and study novel concepts and devices based on acoustooptic and electrooptic effects as well as to advance the performance characteristics of a number of the guided-wave acoustooptic and electrooptic devices with applications to wideband multichannel information processing and communications. During the reporting period very significant progress has been made.

III. SUMMARY OF RESEARCH PROGRESS

During the reporting period significant progresses were made in the following subareas.

1. Very High Scanning-Rate AO Light Beam Deflection and Switching

   During the course of experiments aimed at achieving a higher scanning rate and a large number of beam postion, two transducer configurations capable of producing wideband AO deflection, namely, tilted-finger chirp transducer and curved transducer of varing finger periodicity were discovered.

2. Spectrum Analysis of Very Wideband RF Signals

   A coupled-mode analysis relevant to Guided-Wave AO Spectrum Analysis has been completed. Measurements on number of resolvable channels and frequency resolution were made using a Bragg cell with 680 MHZ bandwidth. Desirable data was obtained.

3. Wideband AO Bragg Cell Using Multiple Tilted Transducer But Without Electronic Phase Shifters

   We have discovered a simple scheme (in conjunction with multiple tilted-transducers) to obtain a broad deflector bandwidth (680 MHz) without requiring electronic phase shifters. This is the largest bandwidth that has been reported.

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   A tilted-finger chirp transducer which had evolved from the multiple tilted-transducers has been shown to be capable of providing wideband AO light beam deflection.

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We can now fabricate SAW transducers with center frequency approaching 1 GHz.

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We have opened up a new area of research in Guided-Wave Acoustooptics which involves channel optical waveguides rather than planar optical waveguides. The premilinary results obtained have been very encouraging. The resulting devices should find a variety of unique applications in future integrated and fiber optic systems such as double-pole-double-throw switching, multiplexing/demultiplexing, heterodyne detection, and fiber optic sensing.

IV. RESEARCH HIGHLIGHTS

1. Very High Scanning-Rate AO Light Beam Deflection and Switching

It has been well recognized that the planar AO Bragg deflector shown in Fig. 1 can provide a variety of important functions in optical communications and signal processing.[1,2] Also, as demonstrated during the last program year, a guided-light beam may be scanned and switched using AO analog (F-M) mode of operation in which the frequency of the electrical drive signal varies linearly with time, namely, a chirp signal. Using this mode of operation we have achieved in our experiments a scanning rate (number of resolvable spots scanned per second) two orders of magnitude higher than that obtainable using digital (random access) mode of operation, namely, 250×10^6 spots/sec versus 1×10^6 spots/sec. Our analysis shows that considerably higher scanning rate and larger number of beam positions can be obtained when a deflector of higher center frequency and wider bandwidth is used. Consequently, wideband AO analog deflectors should pave the way for a number of important applications including: 1. Very high-data rate multiport switching; 2. Very high-data rate optical writing and reading in applications such as facsimile;[3] 3. Optical pulse compression of radar chirp signal;[4] 4. Time-demultiplexing of wideband multichannel optical pulse trains,[2] and 5. High-Speed parallel to serial (spatial to temporal) readout for RF spectra in integrated optic signal processing systems.[5]

In accordance with the above projection, some experiments aimed at demonstrating a higher scanning rate and a larger number of beam positions were carried out using a wide band deflector which utilizes multiple tilted transducers of staggered center frequencies. Although these experiments have, to some degree, verified the prediction we have also discovered that as a result of the displacement of the multiple transducers in the horizontal dimension the deflected light spots are also displaced along the horizontal dimension. This horizontal displacement is not desirable in some applications. While we have

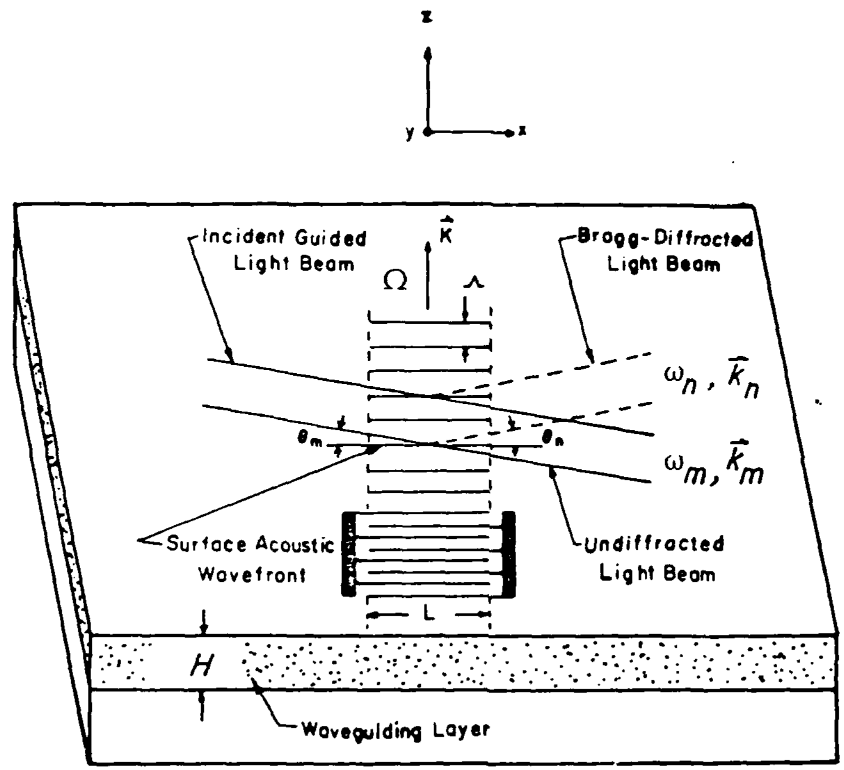


FIG.1 *Guided-Wave Acoustooptic Bragg Diffraction From A Single Surface Acoustic Wave*

devised means to compensate for this displacement, we have also been motivated to discover other deflector configurations which do not have the above undesirable features. As a result, two new wideband deflector configurations have evolved from the multiple-tilted transducers of staggered center frequencies. They are tilted-finger chirp transducer and curved transducer of varying finger periodicity.[2,6] The working principles of these deflector configurations are described in Subsection IV4. It suffices to note here that a considerably smaller displacement in the deflected light spots is expected to occur in these two deflector configurations.

During the next program year we plan to carry out some very high scanning-rate deflection experiments in $LiNbO_3$ waveguides using the tilted-finger chirp transducers just mentioned. In addition, a waveguide lens will be incorporated to focus the deflected light spots on the plane or the edge of the waveguide substrate. If time allows a detector array will also be incorporated to measure the deflected light spots.

2. Spectrum Analysis of Very Wideband RF Signals

As indicated in the original proposal, the tasks of this particular topic are to study, both theoretically and experimentally, the various technical aspects relating to Air Force Avionic Laboratories' on-going program on Integrated Optic Spectrum Analyzers.[7,8] On the theoretical side, a coupled-mode analysis aimed at evaluating the key parameters that relate to wideband acoustooptic RF spectrum analysis in $LiNbO_3$ waveguide has been completed. On the experimental side, emphasis has been placed on realization of planar AO Bragg cells of very large bandwidth and high diffraction efficiency because these two performance characteristics are among the major requirements of the Air Force's spectrum analyzers. For example, a bandwidth of 700 MHz and a diffraction efficiency of 50% per RF Watt are specified in a recent RFP.[8] For this purpose we have continued research toward improving the existing wideband configurations as well as exploring additional configurations. As a result of this effort very significant progress has been made. We have uncovered a simple scheme[2,6] to eliminate the requirement of electronic phase shifters with the wideband configuration which utilizes multiple tilted SAW transducers of staggered center frequency.[9] The effectiveness of this scheme has been verified with a Bragg cell which has a meansured bandwidth of 680 MHz. A detailed description of this progress is given in Section 3. This discovery has considerably increased

the viability of this wideband configuration. As mentioned in Section 1, we had also uncovered a new wideband configuration which utilizes a tilted-finger chirp transducer.[2,6] Bandwidths of 255 MHz[6] and 470 MHz[10] have been measured with the two preliminary Bragg cells which were fabricated. This progress is discussed in Section 4. Since a number of technical problems remain to be answered a detailed study is suggested for the next program year.

3. Wideband AO Bragg Cell Using Multiple Tilted Transducers But Without Electronic Phase Shifters

The transducer arrangement for this wideband configuration is illustrated in Fig. 2. The individual periodic ID transducers are staggered in synchronous (center) frequency and tilted in acoustic propagation direction.[9] The tilt angle between each pair of adjacent transducers is set equal to the difference of the two Bragg angles at the two corresponding center frequencies. Each element transducer is incorporated with a matching network and the transducers are electrically driven in parallel through a power divider. Individual attenuators may also be incorporated between the outputs of the power divider and the inputs of the matching networks to tailor the peak diffraction efficiency at each center frequencies. It is clear that the multiple tilted SAWs generated by such a composite transducer satisfy the Bragg condition in each frequency band and thus enables a broad composite frequency response to be realized.

We now turn to the relative positions of the element transducers. As a result of the difference in the phases of the SAWs generated by the adjacent element tranducers and also the difference in acoustic propagation path (measured from the front edge of the transducers to the interaction region), the individual diffracted lights from the adjacent SAWs may differ in phase for the crossover frequencies. Consequently, adjustable electronic phase shifters were incorporated to compensate for this phase difference and to ensure that the individual diffracted lights add in phase. For example, in the earlier work two phase shifters were used to achieve deflector bandwidths of 358 MHz[9] and 500 MHz.[4]

We have recently discovered that the phase shifters may be eliminated by properly configurring the element transducers, namely, by proper choice of both the horizontal separation and the vertical step between each pair of adjacent element transducers (Fig. 3).[2] For an example involving transducers #1 and #2, the orizontal separation D_s and vertical step height h' are given as follows:

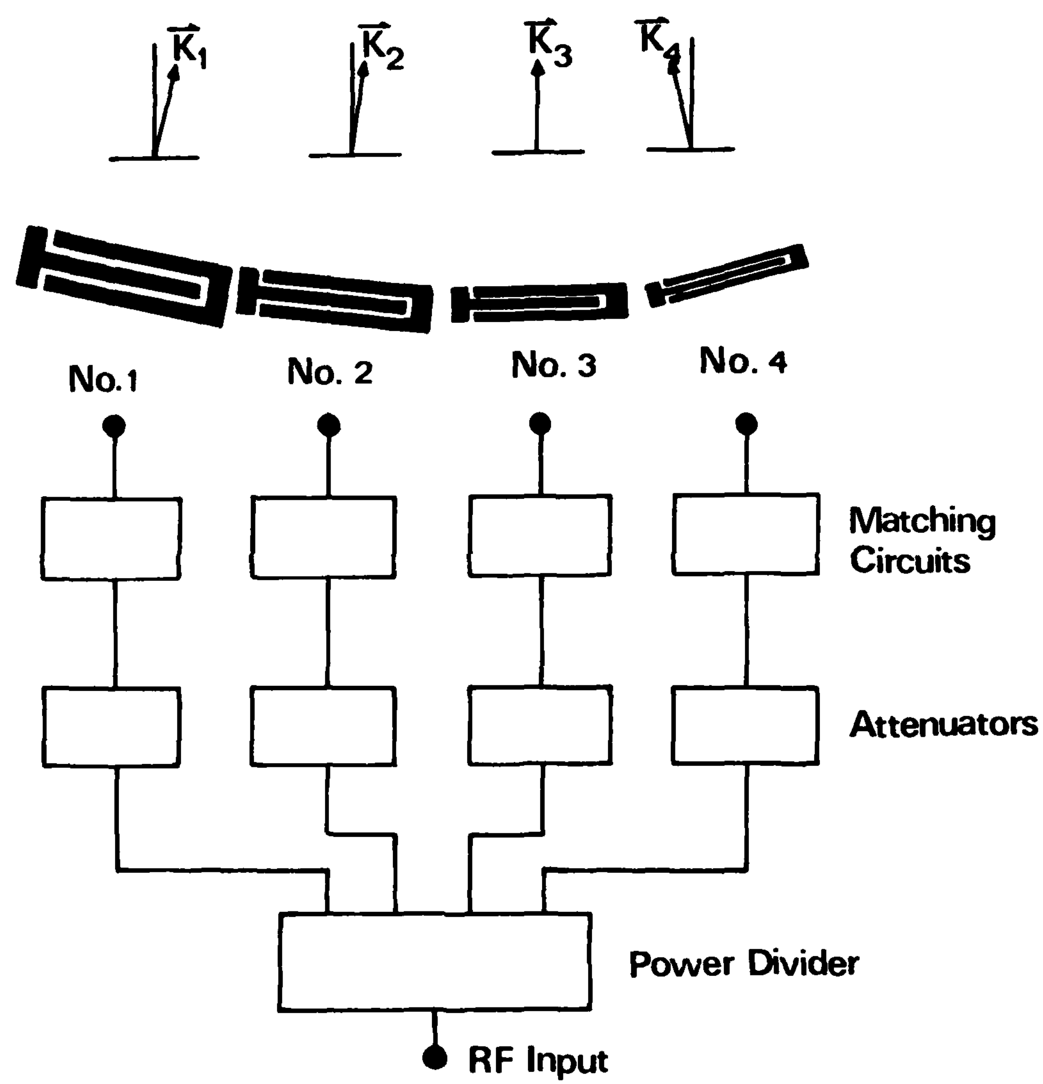


Fig. 2. Multiple Tilted SAW Transducers Of Staggered Center Frequency And RF Driver Circuits

$$D_s = M\left(\frac{2\Lambda_1^2}{\lambda}\right) \tag{1}$$

$$h' = \left(\frac{\lambda}{\Lambda_i} - \frac{\lambda}{2\Lambda_{01}}\right) D_s \tag{2}$$

where λ = wavelength of the light wave in the waveguide

$\Lambda_{01}\ \Lambda_{02}$ = wavelength of the SAW at the center frequency f_{01} for transducer #1 and the center frequency f_{02} for transducer #2, respectively

Λ_i = wavelength of the SAW at the crossover frequency $\simeq (f_{01} + f_{02})/2$

M = integer

$\Delta\theta_B$ = difference of the two Bragg angles at f_{01} and f_{02} $\simeq \frac{1}{2}\lambda\left(\frac{1}{\Lambda_{02}} - \frac{1}{\Lambda_{01}}\right)$.

Note that a proper choice of M is dictated by the apertures of the adjacent element tranducers. The above design formulas can be successively applied to determine the relative locations of all element transducers in the array.

Using the design formulas just described a deflector of 680 MHz bandwidth has been realized most recently in a Y-cut Ti-diffused $LiNbO_3$ waveguide.(6) While the details of this latest development will be reported elsewhere, it suffices to mention here some of the measured results. The deflector utilizes four tilted transducers with center frequencies of 380, 520, 703, and 950 MHz. A rutile prism was used to excite a guided light of TE_0 mode from a He-Ne laser at 0.6328 μm and a second rutile prism was used to couple out both the Bragg diffracted and the undiffracted light beams. Deflected light beam of very good quality was observed. The measured conversion efficiency of the four element transducers are, respectively, -7.5, -7.0, -10, -15 db. The measured frequency response of this deflector is shown in Fig. 4. The corresponding diffraction efficiency is 8% at a total rf drive power of 0.8 watt for the entire 680 MHz bandwidth. Fig. 5 shows the photographs of the deflected light spots obtained with this deflector. The number of resolvable spots of 1000 and a frequency resolution of 0.67 MHz have been measured.(6) Since the measured diffraction efficiency of the deflector with only the first three transducers activated is

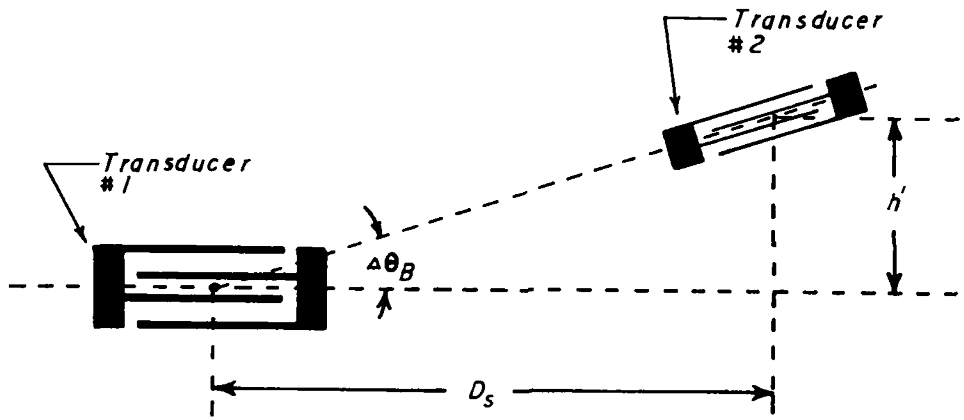


Fig.3 Geometrical Configuration Of Element Transducers In A Frequency — Staggered Tilted Transducer

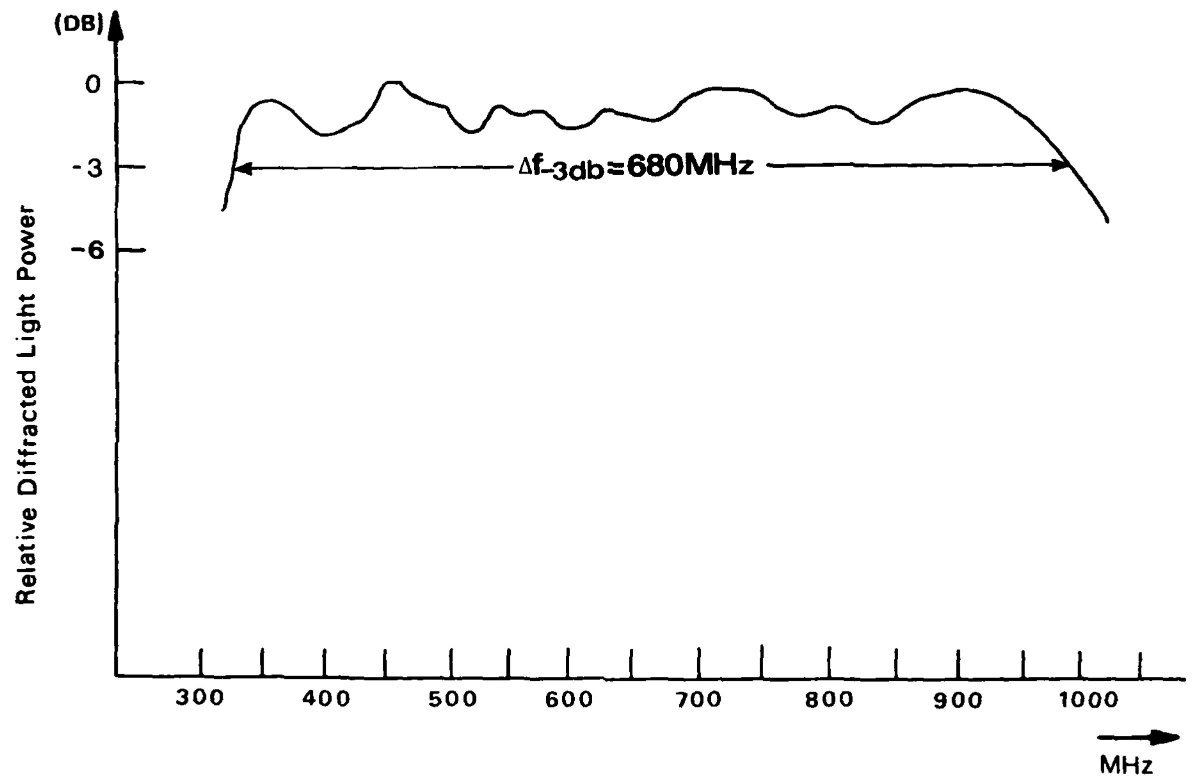
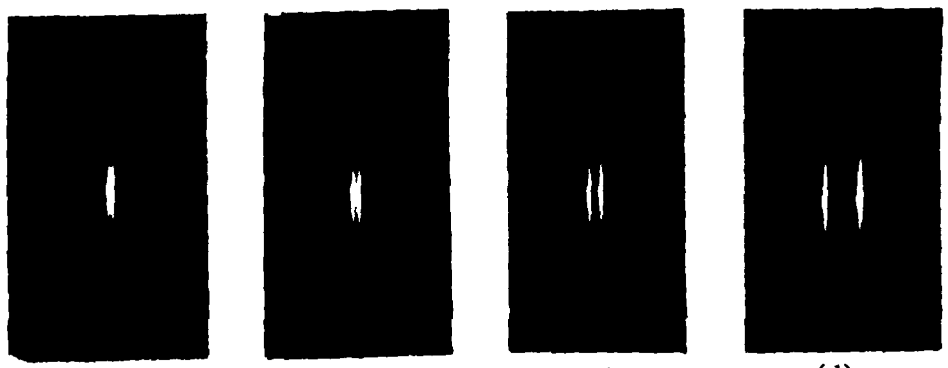


Fig.4 Measured Frequency Response of A Deflector Employing Four Tilted Transducers In A Y-cut $LiNbO_3$ Waveguide



(a) $\delta f = 0.7$ MHz

(b) $\delta f = 1.0$ MHz

(c) $\delta f = 2.0$ MHz

(d) $\delta f = 6.0$ MHz

Fig.5 Deflected Light Spots as a Function of Frequency Separation Between Two RF Drive Signals (Aperture of Incident Light: 6 mm)

nearly five times higher, a considerably better diffraction efficiency can be expected if the conversion efficiency of the fourth transducer (the one with highest center-frequency) is improved to that of the first three. Also, once a better transducer conversion efficiency is achieved a deflector with GHz bandwidth can be realized by increasing the center frequencies of the element transducers. Based on this projection a performance figure of approximately 1 mw electrical drive power per MHz bandwidth with 50% diffraction efficiency and 1 GHz bandwidth should be realizable. Consequently, one of the goals of the future program is to improve the conversion efficiency of transducers at GHz frequency range.

4. Wideband AO Bragg Cell Using a Tilted-Finger Chirp Transducer

The new wideband configuration to be discussed here had evolved from the multiple tilted-transducers just described in the last Subsection. We return to Fig. 2 and consider the situation involving a large number of element transducers. We consider specifically that the element transducers have closely spaced synchronous frequencies and each has a single finger pair. Clearly, under this situation the appropriate tilt angle between each adjacent pair of element transducers will be very small. If we now place all such element transducers together, one behind the other in a line, and connect them electrically in parallel we will have constructed a composite transducer of varying finger periodicity and tilt angle as depicted in Fig. 6. We shall call this composite transducer a "tilted-finger chirp transducer",[(6)] consistent with the common usage of the terminology "chirp transducer" for a transducer of varying finger periodicity.[(11)] Like the conventional chirp transducer the bandwidth of this composite transducer should be relatively large. We also expect that the wavefront of the SAW generated by this composite transducer will track the Bragg condition for the entire frequency band, and thus result in a large AO Bragg bandwidth. Thus, this composite transducer should also be capable of providing a large deflector bandwidth. It should be noted that a conventional chirp transducer of parallel fingers and small aperture can also be employed to obtain a large deflector bandwidth.[(12)] However, in this case the large bandwidth is obtained at a drastically reduced diffraction efficiency. Consequently, a higher diffraction will necessarily require more rf or acoustic drive power, and thus increase the risk of transducer failure as well as deleterious effects due to acoustic nonlinearity.

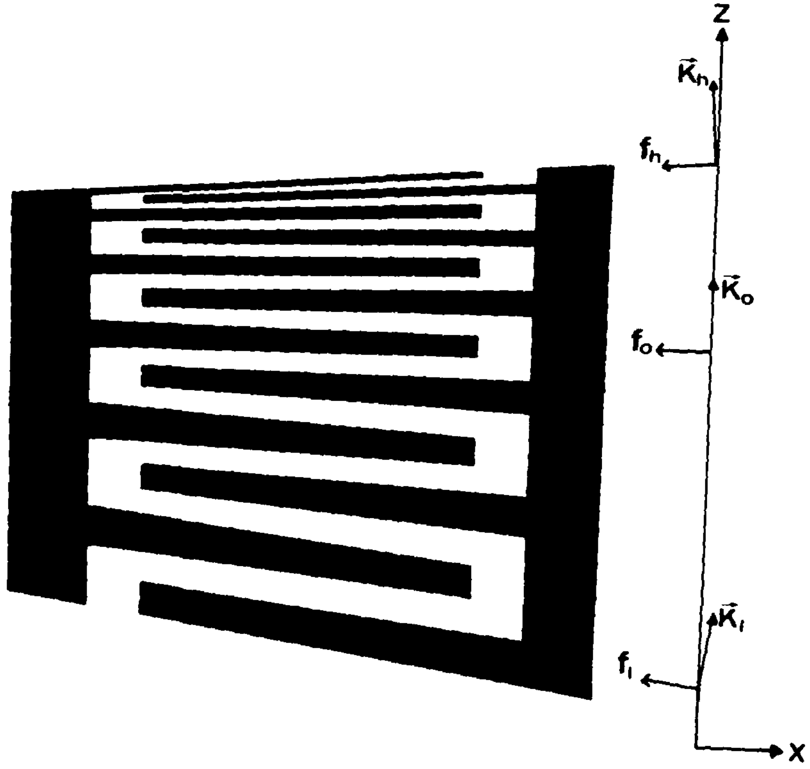


Fig.6 A Tilted–Finger Chirp Transducer Evolved from A Large Number of Tilted Trans– ducers of Staggered Center Frequency

We have recently designed and fabricated a tilted-finger chirp transducer in a titanium-diffused Y-cut $LiNbO_3$ waveguide, and have carried out some Bragg deflection experiments using a He-Ne laser light of TE_0 mode at 6328 Å to verify the concept described above.[6] The synchronous frequency of the fingers was designed to vary linearly from 320 (f_ℓ) at one end to 630 MHz (f_h) at the other. We chose this relatively low frequency range because of our experience with the lower transducer conversion efficiency at the higher frequency range as indicated earlier in Section IV3. The corresponding finger electrode width at the center of the finger aperture varies from 2.7 to 1.4 μm. The transducer contains 51 finger electrodes each with an aperture of 0.55 mm. For simplicity the finger electrodes are tilted and spread out like a fan to cover the range of Bragg angles corresponding to the entire frequency band. The total tilt angle is .74 degree.

The transducer was driven directly with an rf signal generator of 50 ohm source impedance. The measured -3 db transducer bandwidth is 255 MHz. The measured frequency response of the deflector, at an incident angle (shown in the inset) for which the Bragg condition would be satisfied for the entire frequency band, is shown in Fig. 7(a). Fig. 7(b) shows both the measured and calculated frequency responses obtained at a second incident angle (symmetrical with respect to the X-axis as shown in the inset) for which the Bragg condition is satisfied only at 500 MHz. Fig. 7(a) shows a measured -3 db deflector bandwidth of 255 MHz while Fig. 7(b) shows only 150 MHz. This considerable difference in bandwidth clearly indicates that the broad frequency response of the deflector shown in Fig. 7(a) results from fulfillment of the Bragg condition which is facilitated by the tilted-fingers. The measured diffraction efficiency is 16% at a total rf drive power of 200 milliwatts.

Most recently we have also demonstrated a bandwidth of 470 MHz (centered at 615 MHz) and similar diffraction efficiency with a deflector of improved design.[13] In this design, a 1-mm transducer aperture is partitioned into two sections and connected in series electrically. The frequency response of this deflector is shown in Fig. 7(c). The deflector has been subjected to 1 W of CW RF drive power without failure.

In summary, the results described above have shown that a tilted-finger chirp transducer is also capable of providing a large deflector bandwidth with an efficient diffraction. It is clear that a deflector of very large bandwidth can be implemented using a multiple of tilted-finger chirp transducers which

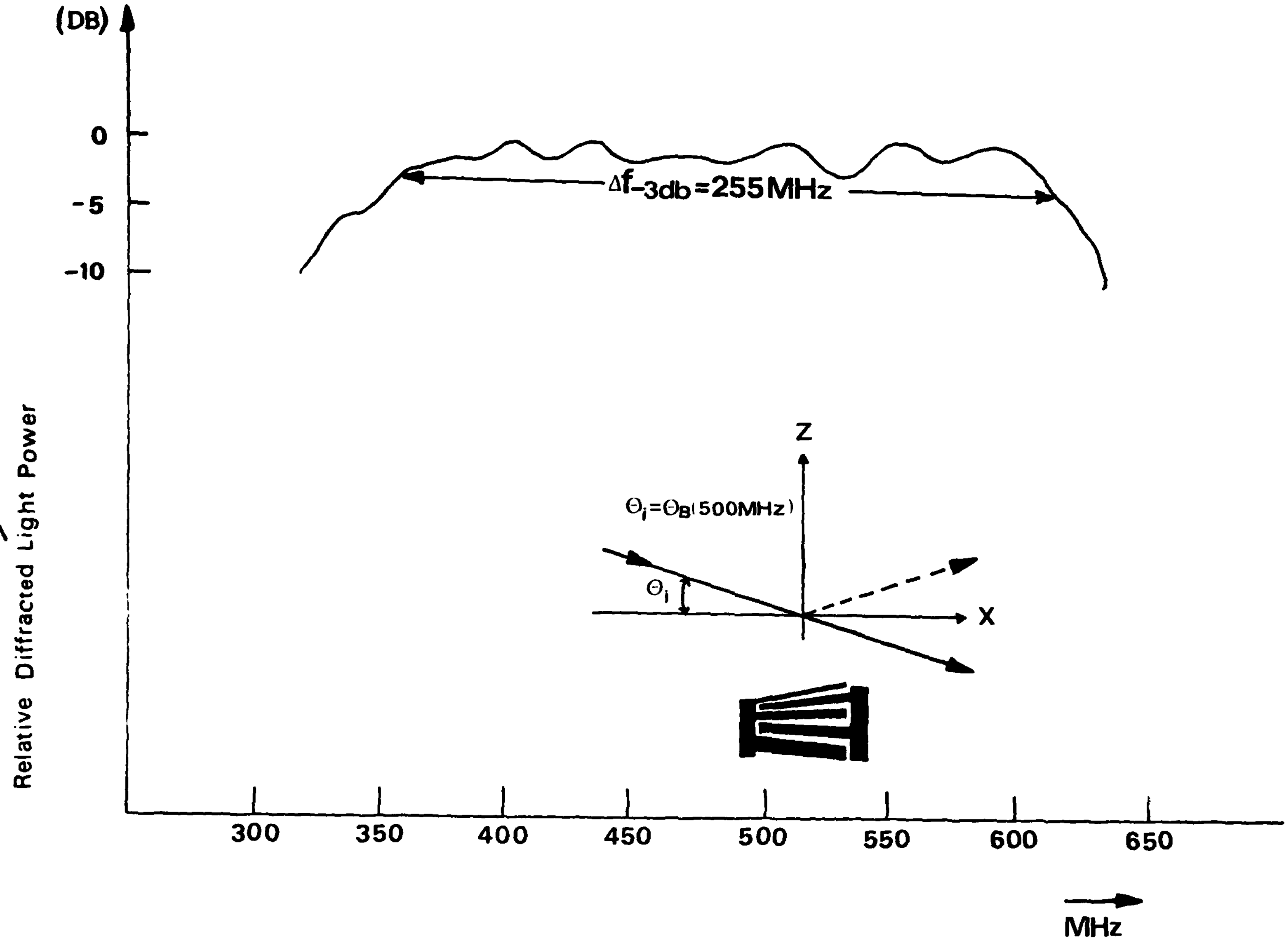


Fig. 7(a) Measured Frequency Response Of The Deflector With Tilted – Fingers At An Optimum Incident Light Angle (Bragg Angle)

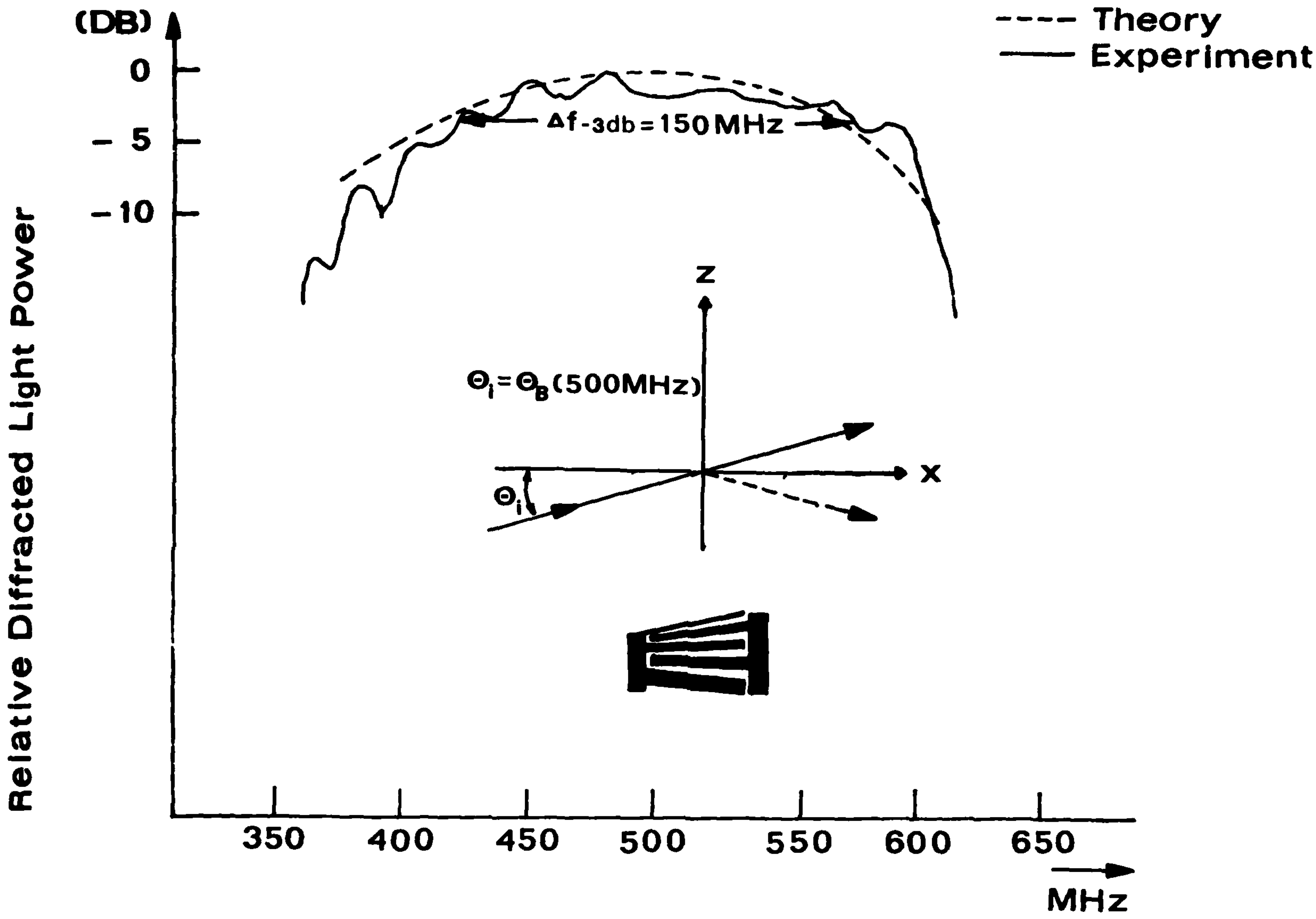


Fig. 7(b) Measured And Calculated Frequency Responses Of The Deflector With Tilted-Fingers At An Incident Light Angle Other Than Optimum

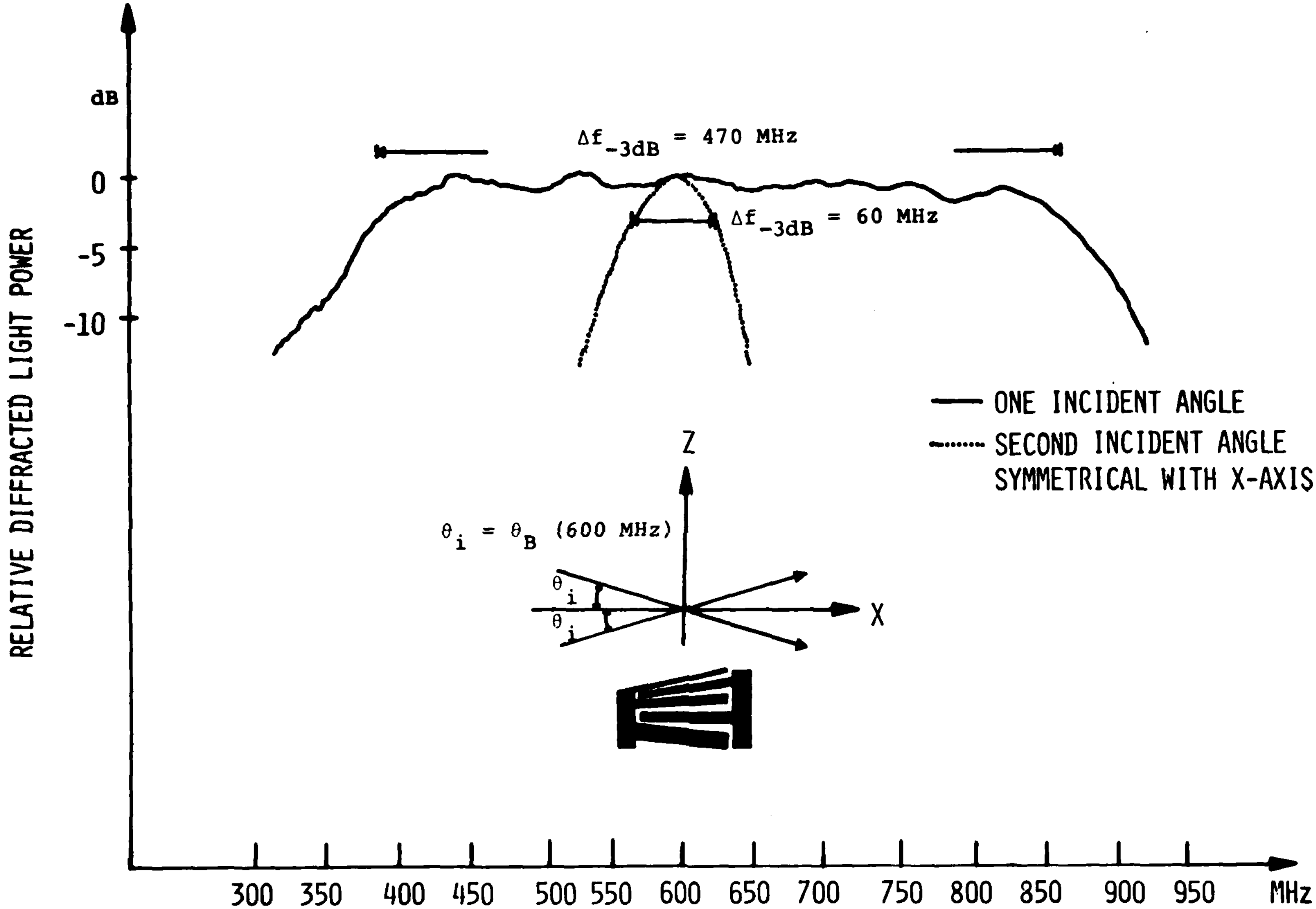


FIG.7(c) MEASURED FREQUENCY RESPONSES OF THE DEFLECTOR (WITH TILTED-FINGERS) AT TWO SYMMETRICAL INCIDENT LIGHT ANGLES (BRAGG ANGLES AT 600 MHz:1.41°)

are tilted properly with respect to each other. In view of this potential and the fact that a number of important technical problems remain to be investigated a detailed study is proposed in the next program year.

5. Improvement in Fabrication Capability

Through an equipment fund from the present AFOSR program we have significantly improved the microfabrication facilities of our laboratory. We can now fabricate surface acoustic wave transducers with center frequency approaching 1 GHz. Although the conversion efficiency of the transducers at the frequency range of 800 to 1000 MHz remains to be improved (please see Subsection IV3), this fabrication capability (in terms of facility and expertise) is unique among the university communities.

6. Acoustooptic Bragg Deflection in Crossed Channel Optical Waveguides

Acoustooptic Bragg deflection involving optical waves and surface acoustic waves (SAW) in planar waveguides has been studied extensively in recent years.(2) The resulting planar devices have also been shown highly useful for wideband multichannel integrated optic communication and signal processing systems.(2) On the other hand, acoustooptic Bragg deflection in channel waveguides in which the optical waves are confined in the channels has received no attention heretofore. Nevertheless, the resulting channel devices are potentially more useful in fiber optic systems because of the compatibility in dimension and, thus, the relative simplicity in facilitating the coupling between the channel waveguide and the optical fiber. We have demonstrated simultaneously a high diffraction efficiency and a large deflector bandwidth in a device which consists of two crossed channel guides and one SAW transducer on a Y-cut $LiNbO_3$ substrate.(14) This work was also supported in part by the NSF and the AROD because the device to be discussed utilizes the crossed channel waveguides which were developed through these two agencies.

One interaction configuration of great interest is shown in Fig. 8. The center frequency of the SAW generated by the transducer is such that the corresponding Bragg angle is equal to one half of the intersection angle of the two crossed channel waveguides. An optical wave incident at guide 1 is Bragg diffracted by the moving optical grating induced by the SAW in the intersection region. Consequently, a portion of the incident light is deflected to guide 2.

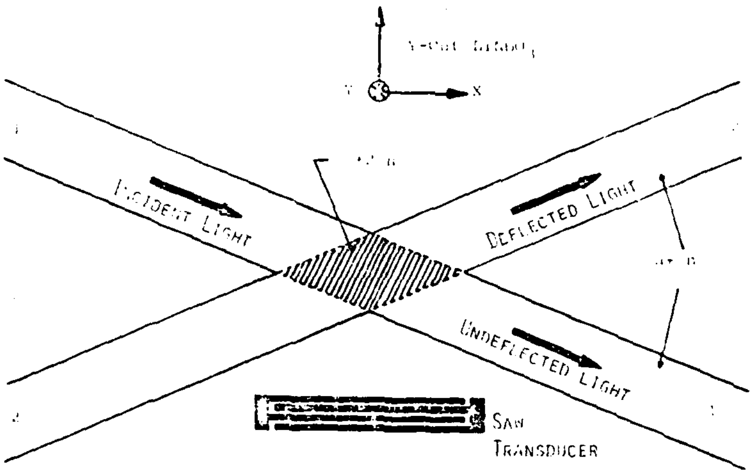


Fig.8 ACOUSTOOPTIC BRAGG DEFLECTION FROM SURFACE ACOUSTIC WAVE IN TWO CROSSED CHANNEL WAVEGUIDES.

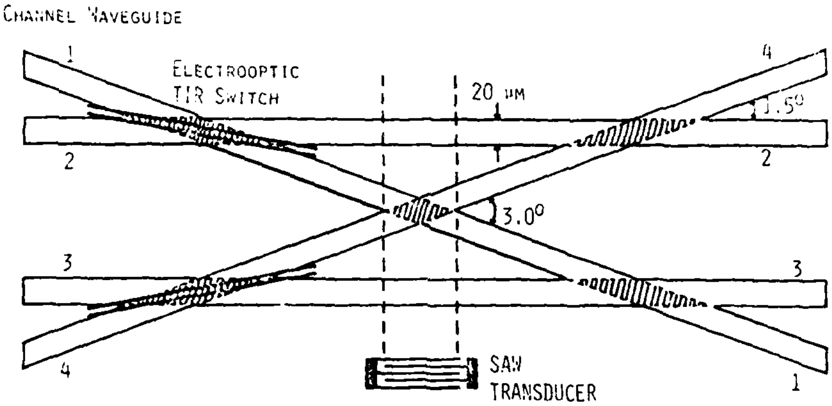


Fig.9(a) ACOUSTOOPTIC BRAGG DEFLECTION IN CHANNEL OPTICAL WAVEGUIDES USING A SWITCHING NETWORK.

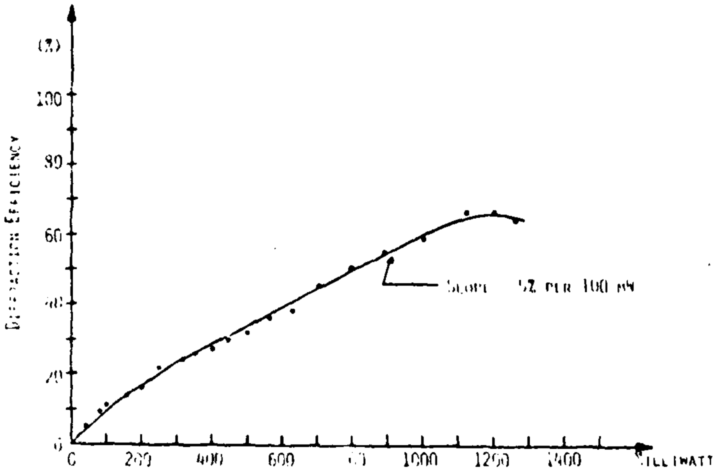


Fig.9(b) Bragg Diffraction Efficiency vs. Electrical Drive Power at a Constant Acoustic Frequency of 634 MHz.

The frequency of the deflected light is up-shifted by an amount equal to the acoustic frequency. Similarly, an optical wave incident at guide 2 will have portion of its intensity deflected to guide 1 and have the frequency of the deflected light down-shifted by the same amount. Such a device configuration will have a variety of unique applications in future integrated and fiber optic systems such as double-pole-double-throw switching, time-division multiplexing and demultiplexing, and heterodyne detection. In the last application, the frequency-shifted light can be conveniently used as a reference signal (local oscillator) in connection with optical communications and fiber optic sensing. It is to be noted that fiber optic sensing is a subject of great current interest.

The basic device structure of Fig. 8 was fabricated initially and tested using a He-Ne laser at 6328 Å. However, because of severe interferences from the out-diffused modes[(15)] we were unable to obtain satisfactory data with this basic device structure.

In order to alleviate this undesirable interference we have subsequently fabricated a device structure of higher complexity as shown in Fig. 9a. Note that except for the SAW transducer this device structure is identical to the 4x4 switching network[(16)] being explored under the AROD Grant. The interference due to the out-diffused modes is greatly reduced by incorporating a TIR switch at the intersection region of guides 1 and 2 which serves to modulate only the light confined in the channel waveguide. Thus, in the acoustooptic deflection experiment the incident light in guide 2 is first intensity-modulated by applying a square-wave voltage to the TIR switch 1. The light which has been switched to guide 1 is subsequently Bragg diffracted by the SAW generated by the transducer. The center frequency of the SAW is 634 MHz, appropriate for the 3.0^{o} intersection angle between guide 1 and guide 4. Ten finger pairs of 0.77 mm aperture are used in the transducer.

A diffraction efficiency of up to 67% has been obtained using an rf power of 800 mw (see Fig. 9b).[(14)] Since the measured conversion efficiency of the transducer is -12 db and a conversion efficiency of -6 db had been routinely demonstrated with this type of transducer in this laboratory, it should be possible to reduce this drive power by a factor of 4. A -3 db deflector bandwidth of 71 MHz has been measured. Finally, when acting as an optical switch a switching time (defined as the time between 0 and 100% points) of 25 nanoseconds has been measured.

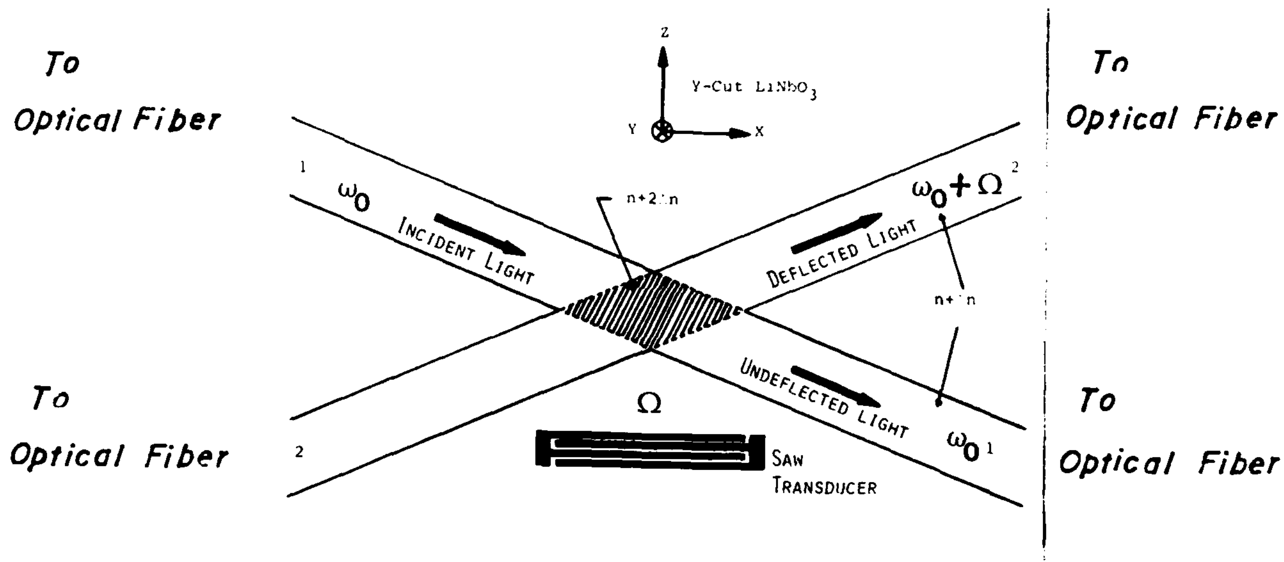


Fig.10 *Integrated Optic — Fiber Optic Module For Heterodyne Detection And Sensing*

V. LIST OF PUBLICATIONS AND RESEARCH IMPACT RESULTING FROM AFOSR SUPPORT

A. Publications

1. C.S. Tsai, I.W. Yao, B. Kim, and Le T. Nguyen, "Wideband Guided-Wave Anisotropic Acoustooptic Bragg Diffraction in $LiNbO_3$ Waveguides," 1977 International Conference on Integrated Optics and Optical Fiber Communication, Technical Digest, pp. 57-60, July 18-20, Tokyo, Japan.

2. C.S. Tsai, Le T. Nguyen, B. Kim, and I.W. Yao, "Guided-Wave Acoustooptic Signal Processors for Wideband Radar Systems," Invited Review Paper, Proceedings of the Symposium on Effective Utilization of Optics in Radar Systems, Huntsville, Alabama, September 27-29, SPIE, Vol. 128, 68 (1977).

3. C.S. Tsai, "Thin-Film Acoustooptics Interactions and Devices," Invited Paper, 94th Annual Meeting of the Acoustic Society of America, Paper D5, Dec. 12-16, 1977, Miami Beach, Florida, The Journal of Acoustic Society of America, Vol. 62, Supplement No. 1, p. S11.

4. C.S. Tsai, Le T. Nguyen, and C.C. Lee, "Optical Pulse Compression and Very High-Speed Light Beam Scanning Using Guided-Wave Acoustooptic Bragg Diffraction," 1978 Topical Meeting on Integrated and Guided-Wave Optics, Technical Digest, pp. TuC3-1 to -4, January 16-18, Salt Lake City, Utah.

5. C.S. Tsai, C.C. Lee, and I.W. Yao, "Wideband Integrated Optic Signal Processors," SPIE, Vol. 154, Real-Time Signal Processing, pp. 60-63 (Aug. 1978).

6. B. Kim and C.S. Tsai, "Thin-Film Tunable Optical Filtering Using Noncollinear Acoustooptic Interaction in $LiNbO_3$ Waveguides," IEEE J. Quantum Electronics, Vol. QE-15, 642-647 (July 1979).

7. C.C. Lee and C.S. Tsai, "An Acoustooptic Readout Scheme for Integrated Optic RF Spectrum Analyzer," 1978 Ultrasonics Symposium Proceedings, IEEE Cat. No. 78CH1344-1SU, pp. 79-81.

8. C.S. Tsai, "Planar Acoustooptic Bragg Modulators for Wideband Integrated Optic Signal Processings and Communications," Invited Paper, IEEE Trans. on Circuits and Systems, Special Issue on Integrated and Guided-Wave Optical Circuits and Systems, Vol. CAS-26, 1072-1098 (December 1979).

9. C.S. Tsai, "Integrated Acoustooptical Circuits for Real-Time Wideband Signal Processing," Invited Paper, presented at the 1979 International Solid-State Devices Conference, August 27-29, Tokyo, Japan, (To be published in Japanese Journal of Applied Physics, April 1980).

10. C.S. Tsai, "Real-Time Optical Data Processing Using Integrated Optics Technology," Invited Paper, Proceedings of International Specialist Seminar on "Case Studies in Advanced Signal Processing," IEEE Conference Publication # 180, pp. 204-215, September 18-21, 1979, Peebles, Scotland.

11. C.C. Lee, K.Y. Liao, C.L. Chang, and C.S. Tsai, "Wideband Guided-Wave Acousto-Optic Bragg Deflector Using a Tilted-Finger Chirp Transducer," IEEE J. Quantum Electron., Vol. QE-15, 1166-1170 (October 1979).

12. K.Y. Liao, C.L. Chang, C.C. Lee, and C.S. Tsai, "Progress on Wideband Guided-Wave Acoustooptic Bragg Deflector Using a Tilted-Finger Chirp Transducer," Proc. of 1979 Ultrasonics Symposium, pp. 24-27, IEEE Cat. No. 79CH1482-9SU.

13. C.S. Tsai, C.C. Lee, and B. Kim, "A Review of Recent Progress on Guided-Wave Acoustooptics With Applications to Wideband Communications and Signal Processing," Technical Digest of the 1980 Topical Meeting on Guided-Wave and Integrated Optics, January 28-30, Incline Village, Nevada, pp. ME1-1 to -4.

14. C.S. Tsai, C.L. Chang, C.C. Lee, and K.Y. Liao, "Acoustooptic Bragg Deflection in Channel Optical Waveguides," Post-Deadline Paper, 1980 Topical Meeting on Integrated- and Guided-Wave Optics, January 28-30, Incline Village, Nevada, pp. PD7-1 to -4.

15. C.S. Tsai, "Acoustooptic Signal Processing Using Integrated Optics," Invited Paper, IEEE Mini-Special Issue on Acousto-Optic Signal Processing, December 1980; Editor, A. VanderLugt.

B. Invited Workshop/Seminar/Conference Papers

1. "Surface Acoustooptic Devices-Fundamentals and Wideband Applications," Workshop on Applications of Integrated Optics to Missile Guidance, April 18-19, 1978, Redstone Arsenal, Alabama; Also, published in Workshop Proceedings, pp. I6-1 to -18.

2. "Signal Processing Devices Using Integrated Optics," Gordon Research Conference on Coherent Optics and Holography, June 18-23, Santa Barbara, California (1978). Summary published in Science, 1979.

3. "Integrated Acoustooptic Circuits for Real-Time Wideband Signal Processing," Third International Conference on Solid State Devices, August 27-29, 1979, Tokyo, Japan.

4. Representing the Area of Integrated Optic Signal Processing, International Specialist Seminar on "Case Studies in Advanced Signal Processing," Sponsored by IEE, England, September 18-21, 1979, Peebles, Scotland.

5. "Time-Integrating Correlation Using Integrated Optics," Optical Signal Processing for C^3I, October 29-30, 1979, Boston, MA, to appear in SPIE, Vol. 209.

6. "Guided-Wave Acoustooptic Device Technology," Conference/Workshop on Acousto-Optic Bulk Wave Devices, November 27-29, 1979, Naval Postgraduate School, Monterey, California, to be published in SPIE, Vol. 214.

7. "Wideband Real-Time Signal Processing Using Integrated Optics Technology," 1980 IEEE International Symposium on Circuits and Systems, Houston, Texas, April 28-30.

8. "A Review on Acoustooptic Signal Processing Using Integrated Optics Technology," AROD Workshop on Optical Information Processing, May 20-22, 1980, Lubbock, Texas.

9. "A Review on Guided-Wave Acoustooptics," 1980 International Specialist Workshop on Optical Waveguides, Sept. 13-15, Portmeirion, Wales, United Kingdom.

C. Ph.D. Theses

1. B. Kim, "A Study on Selected Wideband Guided-Wave Acoustooptic and Electrooptic Devices," April 1979.

2. C.C. Lee, "Integrated Optics for RF Spectral Analysis and Acoustic Microscopy for Study of Material Joints," July 1979.

D. Invention Disclosures

Two invention disclosure have been submitted to AFOSR.

E. Impacts of Research

The wideband guided-wave acoustooptic Bragg cells which have been explored under the previous and current AFOSR supports are being considered for engineering development by the Air Force Avionics Laboratories. Please see RFP # F33615-80-R-1048 entitled, "Wideband Acousto-Optic Bragg Cell Development," dated October 18, 1979. This principal investigator has also been asked by Westinghouse, Motorola, General Electric, and Battelle to provide technical details and consulting services in regard to these wideband Bragg cells. A number of researchers from the United Kingdom, Europe, Australia, and Japan have also come to observe the actual operation of the Bragg cells. Most recently, Battelle Columbus has also started to use these wideband Bragg cells for commercial applications.

VI. REFERENCES

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2. C. S. Tsai, "Guided-Wave Acoustooptic Bragg Modulators for Wideband Integrated Optic Communications and Signal Processings," IEEE Trans. on Circuits and Systems, Special Issue on Integrated and Guided Wave Optical Circuits and Systems, Vol. CAS 26, 1072-1098 (Dec. 1979); Edited by H.F. Taylor.

3. L.C. Foster, C.B. Crumly, and R.L. Cohoon, "A High-Resolution Linear Optical Scanner Using a Traveling-Wave Acoustic Lens," Appl. Opt., Vol. 9, 2154 (September 1970).

4. C.S. Tsai, Le T. Nguyen and C.C. Lee, "Optical Pulse Compression and Very High-Speed Light Beam Scanning Using Guided-Wave Acoustoopic Bragg Diffraction," 1978 Topical Meeting on Integrated and Guided-Wave Optics, Jan. 16-18, Salt Lake City, Utah, Technical Digest, pp. TuC3-1 to -4, (To be submitted to Appl. Phys. Lett., for publication).

5. C.C. Lee and C.S. Tsai, "An Acoustooptic Readout Scheme for Integrated Optic RF Spectrum Analyzer," 1978 Ultrasonics Symposium Proceedings, IEEE Cat. No. 78CH1344-1SU, pp. 79-81.

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8. RFP #F33615-80-R-1048, Entitled, "Wideband Acousto-Optic Bragg Cell Development," dated Oct. 1979; Issued by Air Force Avionics Laboratories.

9. C.S. Tsai, M.A. Alhaider, Le T. Nguyen, and B. Kim, "Wideband Guided-Wave Acoustooptic Bragg Diffraction and Devices Using Multiples Tilted Surface Acoustic Waves," Proc. IEEE, 64, 318 (March 1976).

10. K.Y. Liao, C.L. Chang, C.C. Lee, And C.S. Tsai, "Progress on Wideband Guided-Wave Acoustooptic Bragg Deflector Using a Tilted-Finger Chirp Transducer," to appear in the 1979 IEEE Ultrasonics Symposium Proceedings, IEEE Cat. #79CH1482-9SU.

11. See, for example, R.H. Tancrell and M.G. Holland, "Acoustic Surface Wave Filters," Proc. IEEE, 59, 393-409 (March 1971); W.R. Smith, H.M. Gerard, and W.R. Jones, "Analysis and Design of Dispersive Interdigital Surface Wave Transducers," IEEE Tran., MTT-20, 458-471 (1972).

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